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Matlab + Compressive Sensing + Scanning Electron Microscopy

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Overview – How we use Matlab for Big Data Acquisition

- **Life Science, Electron Microscopy**
- **Matlab Integration: Image Acquisition Stability**
- **Compressive Sensing Basics**
- **Image Acquisition with CS**
- **Matlab: Reconstruction Algorithms**
- **Matlab Integration: Integration to Acquire Big Data**

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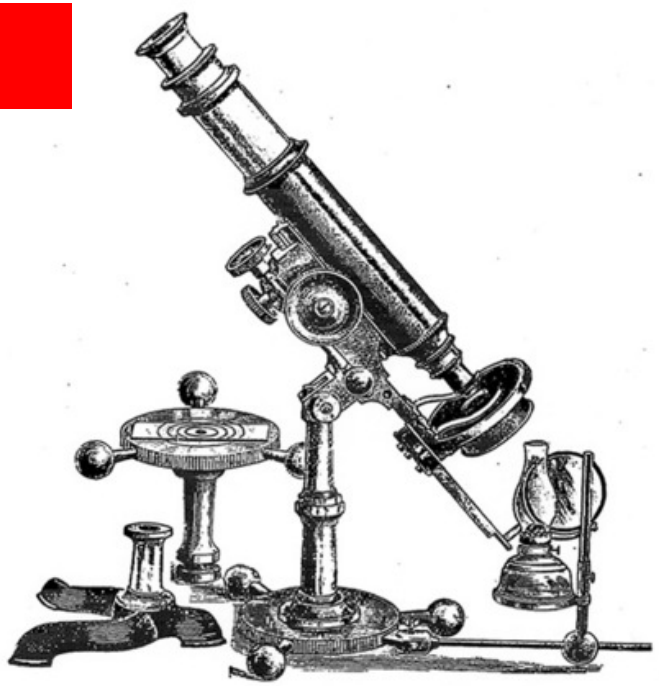


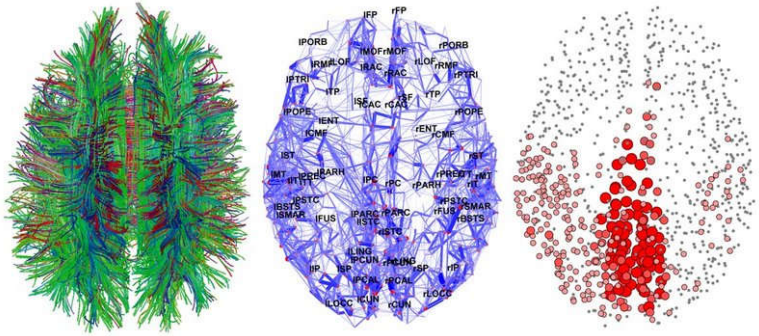
THE GRIFFITH CLUB MICROSCOPE.

Electron Microscopy for Life Science

Human Connectome Project (USA launched 2010 to map wiring human brain)

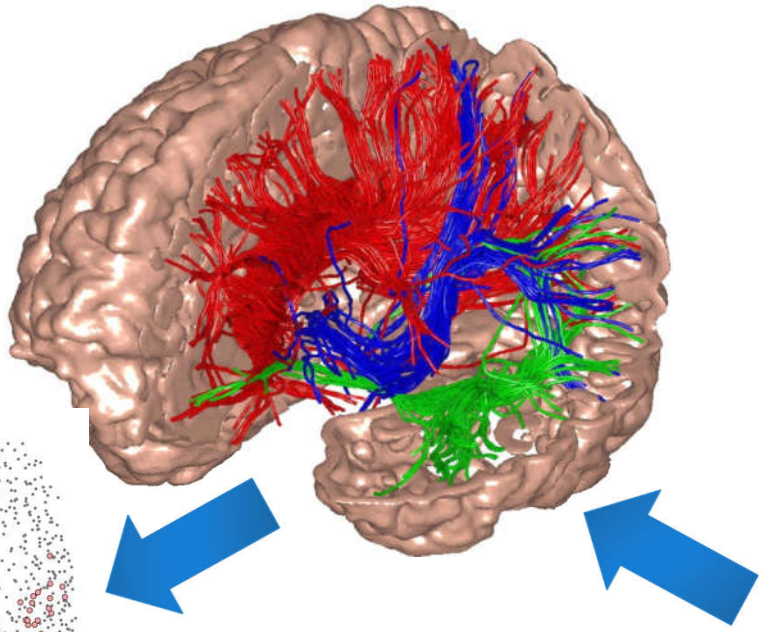
Connectome

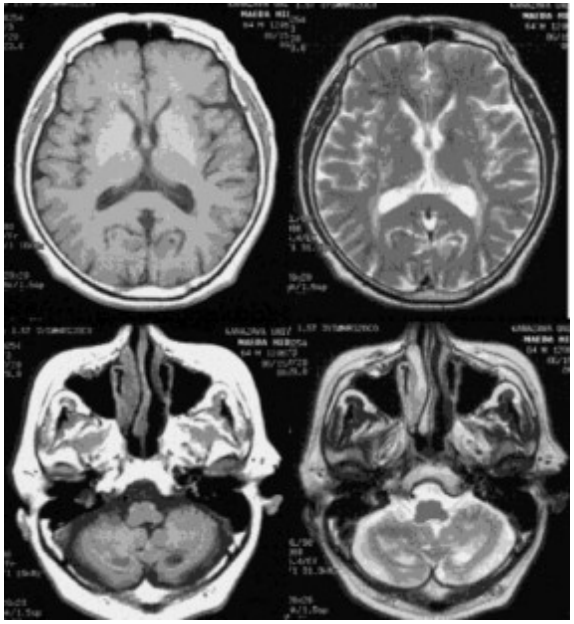
Sum of all brain's connections



- Increased interest to understand the brain functionality

From Connections to Cognition





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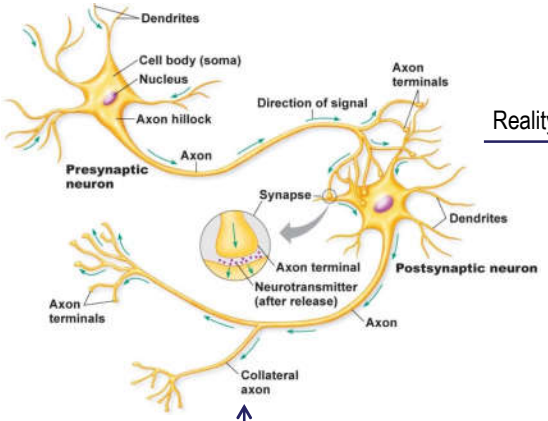
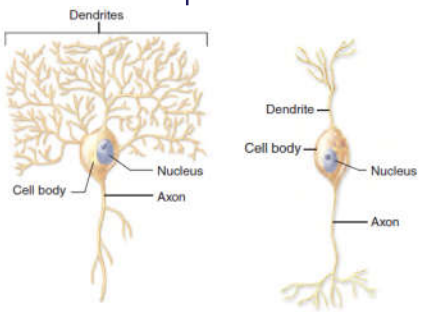
Brain investigation example

Neurons and their connections - synapses

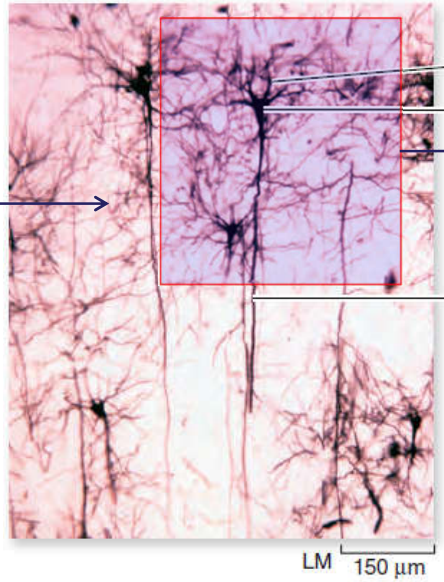


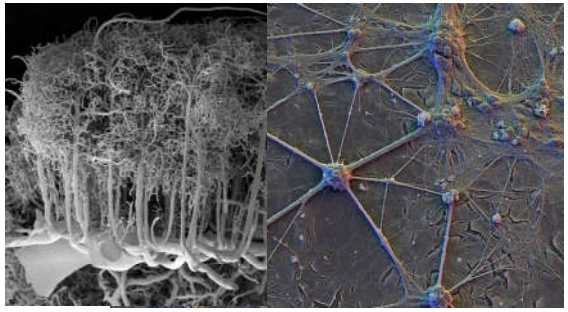
Synapses



Neurons

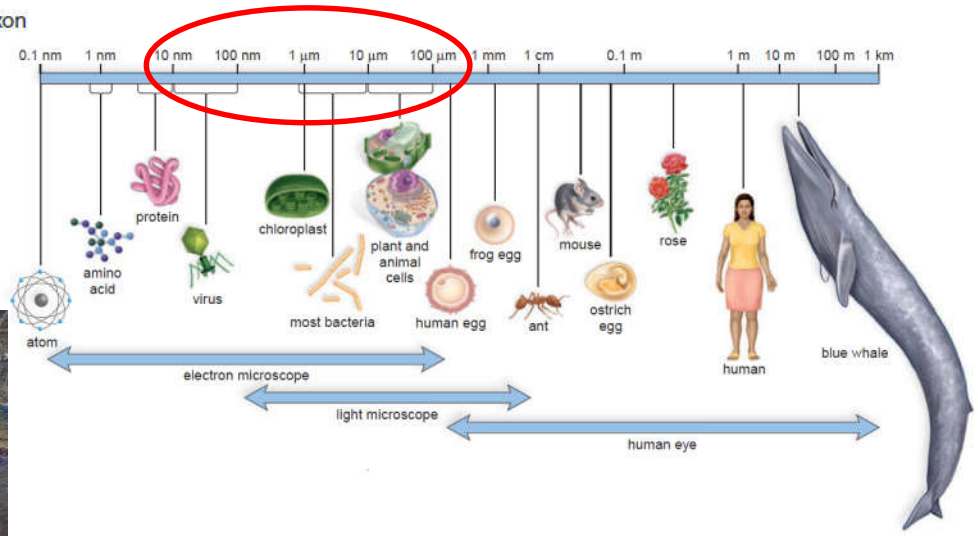
Reality



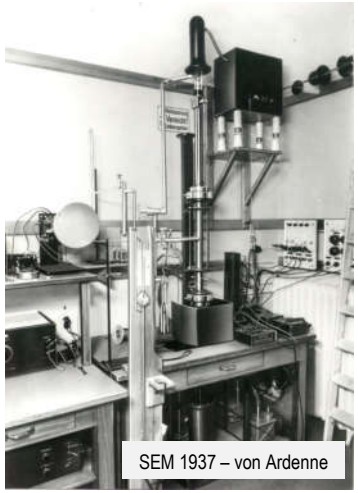


Expected constraints

Volume size ~ 300-500um
Details ~ 10nm

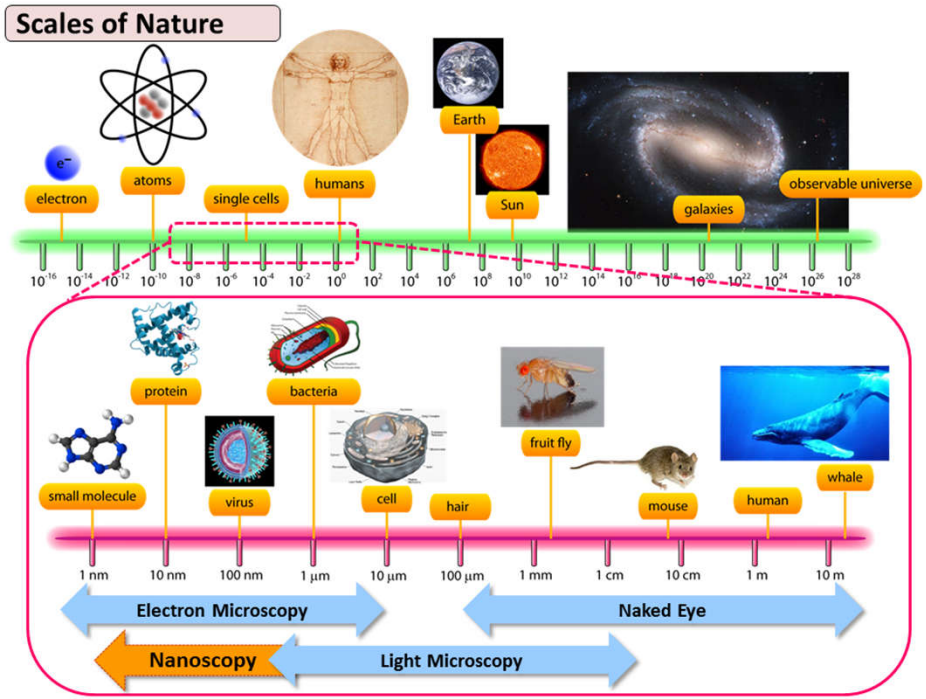


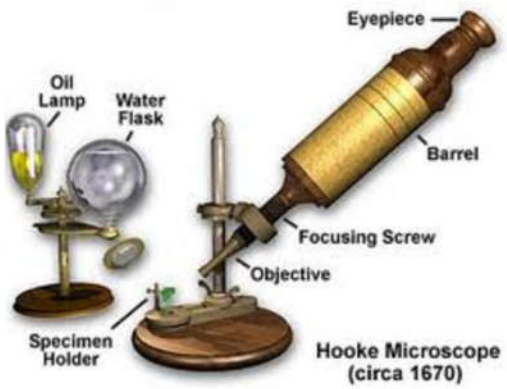
Which tool for Imaging?



SEM 1937 – von Ardenne

TEM 1931 – Knoll, Ruska

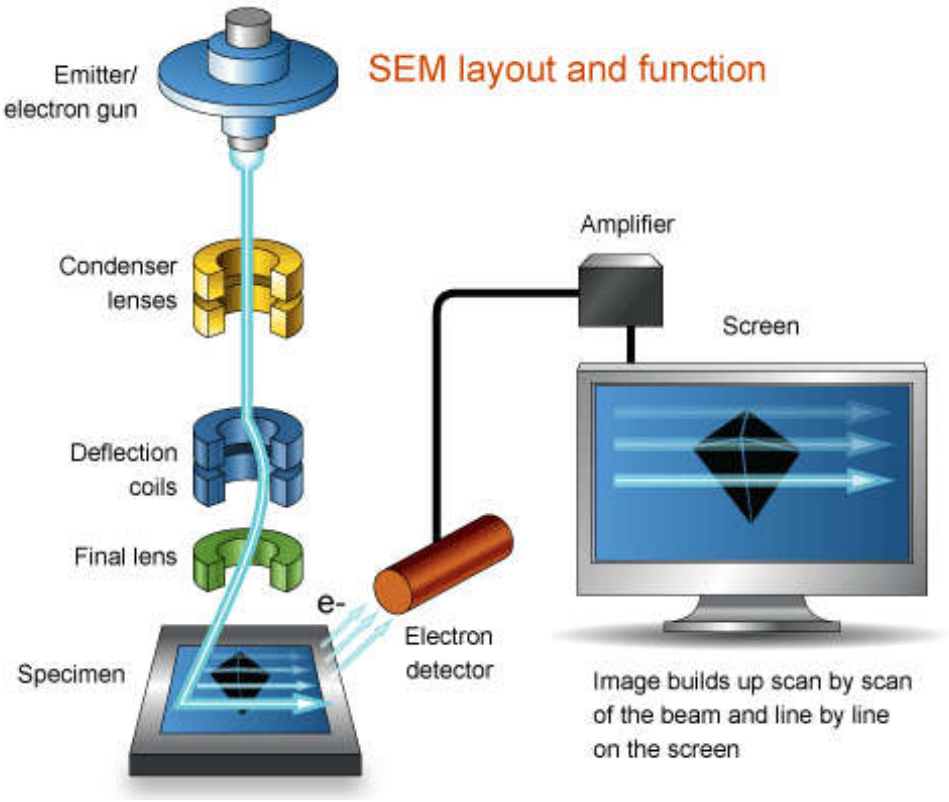


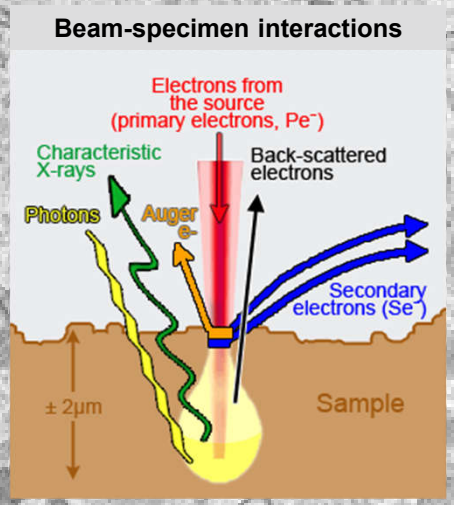


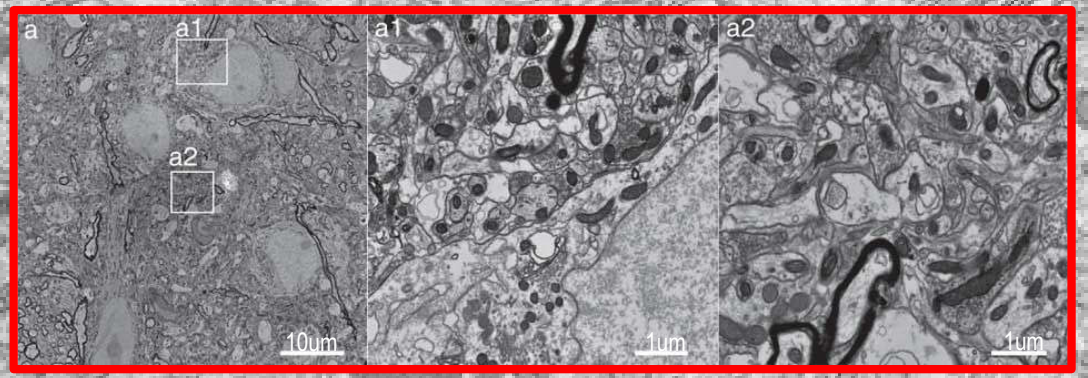
This state-of-the-art microscope contains accessories for DIC, fluorescence, polarized light, phase contrast, and photomicrography using several film formats and digital image capture.

The Olympus Provis AX-70 (circa 1998)

Very Short introduction to Scanning Electron Microscopy







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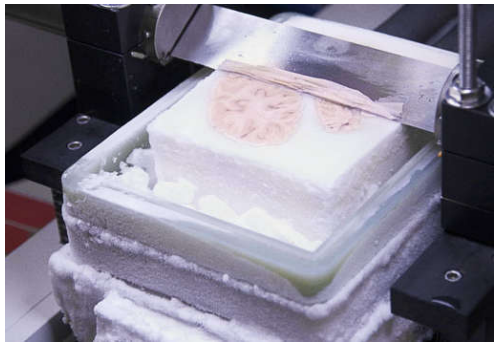
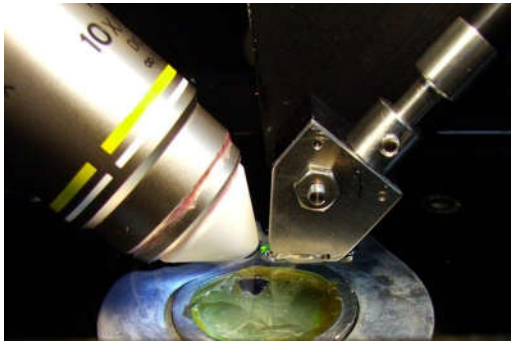
Brain Reverse Engineering

- Reverse engineering is one of the most important techniques

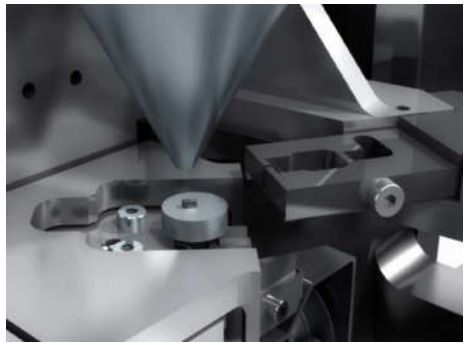
Knife
1mm slice



Blade
70um slice



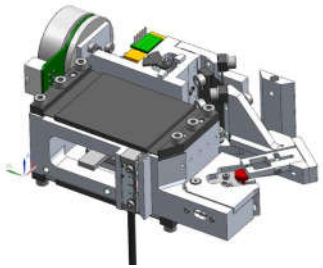
Knife-edge, SEM
300-500nm slice
full mouse brain about 100 hours

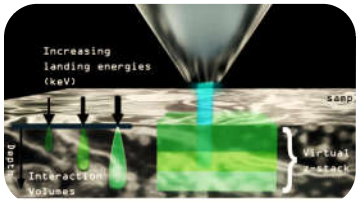


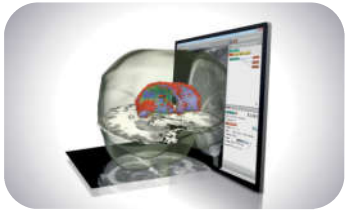
Diamond knife, SEM
25-50nm slice

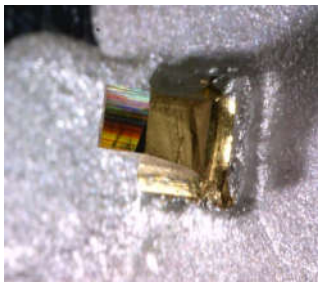
Data acquisition workflow

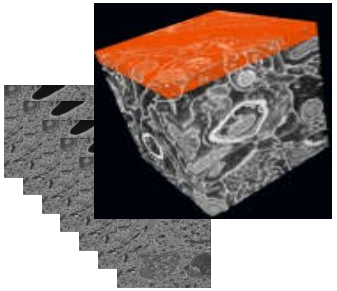
VolumeScope

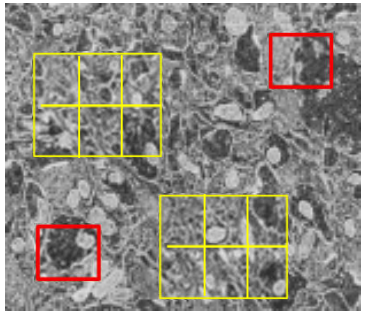


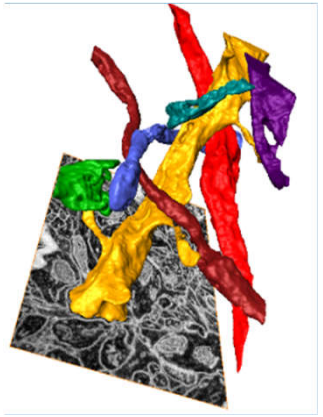












Teneo SEM **Microtome**

Hardware

Multi-Energy Reconstruction **MAPS** **AMIRA**

Software

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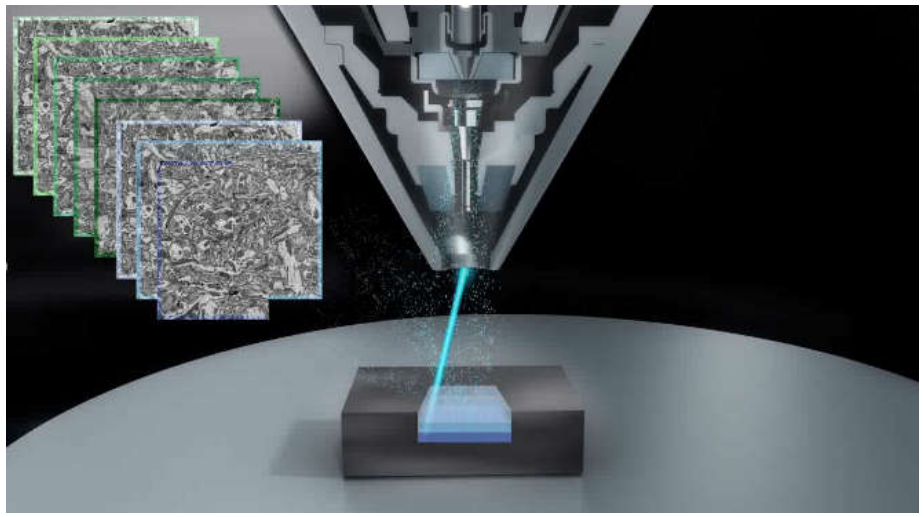
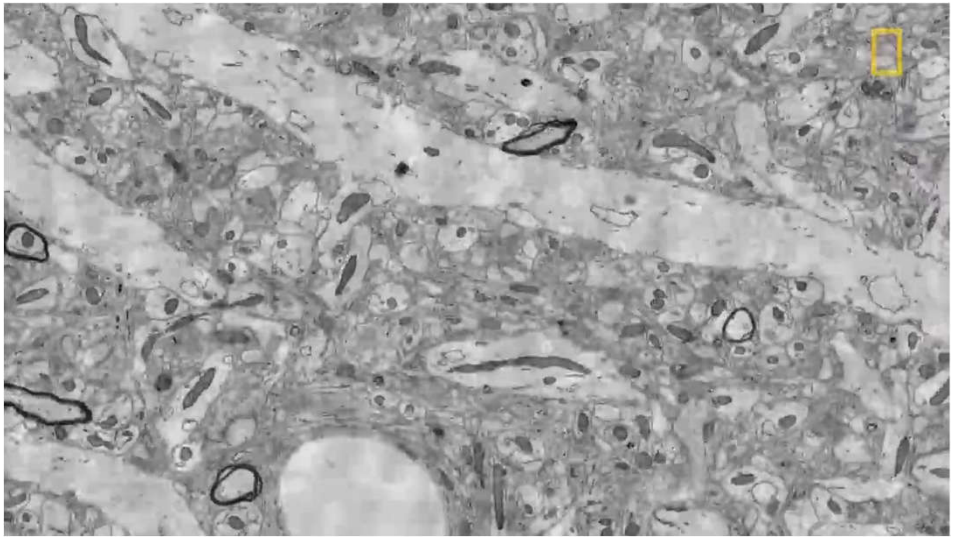
Data acquisition workflow overview - movies

VolumeScope data acquisition



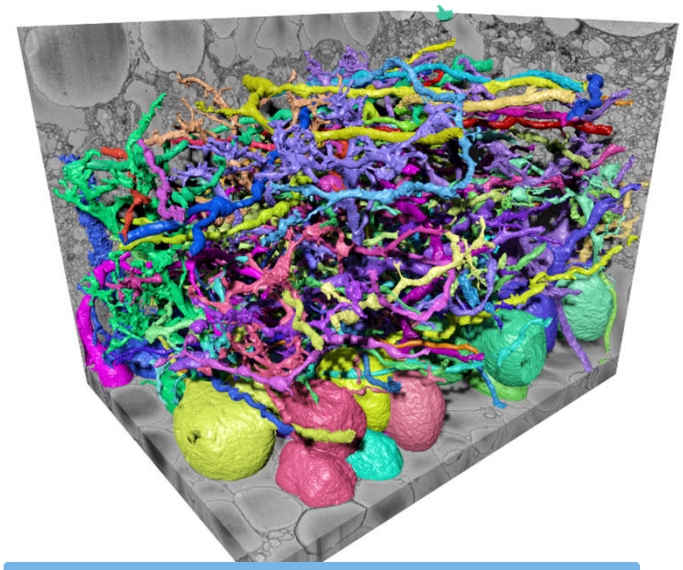


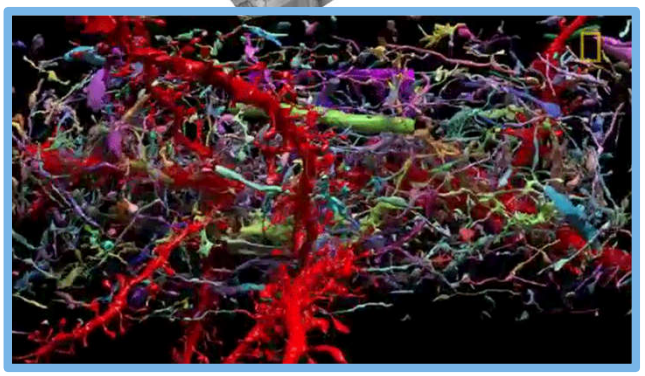
Neuron reconstruction
(from National Geographic, Lichtman)

Acquisition timing example

Volume size ~ 300-500um
Details ~ 10nm

Acquisition	Dwell time	100ns	1us
Single section image	Pixel resolution	32-64k	32-64k
	Data size	2 – 8 GB	2 – 8 GB
	Acquisition time	2-8 m	20-80 m
Full 3D volume	Data size	64 - 512 TB	**64 - 512 TB**
	Acquisition time	**38 – 304 d**	**380 – 3040 d**





- No cutting
- No tiling involved – No stage movements
- No auto-functions - No processing
- Single 16bits data instance
- No failure

MPI:
Denk, Helmstaedter:
13kx50kx50k = 33TP
8 weeks acquisition;
2years to reconstruct

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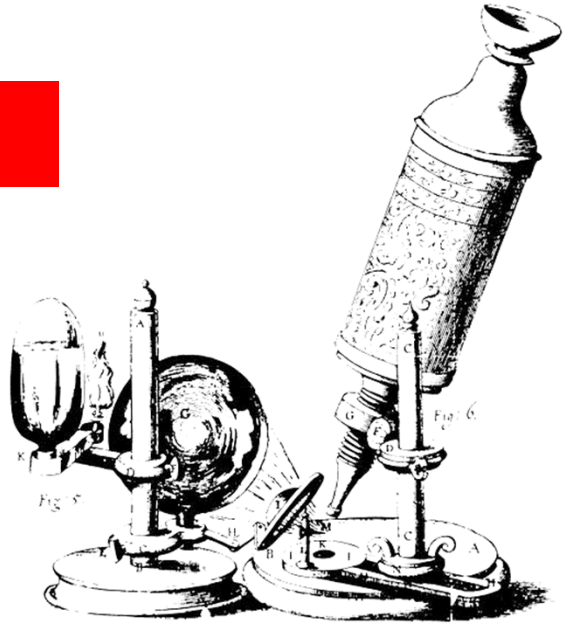
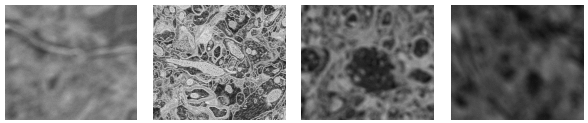


Why do we need auto-functions?

Different imaging conditions (beam energy, working distance, …)

Without any adaptation



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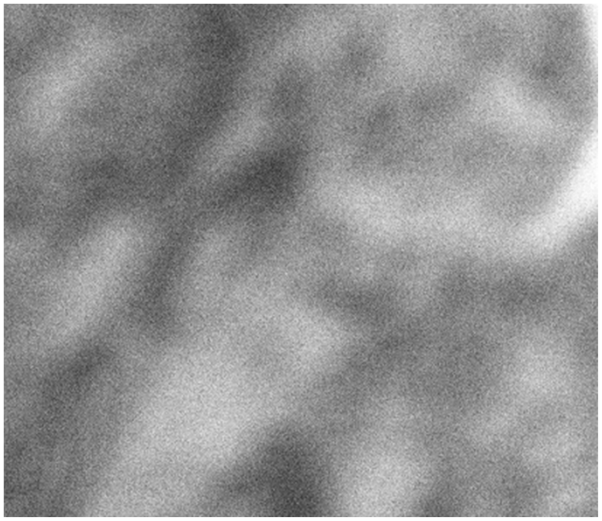
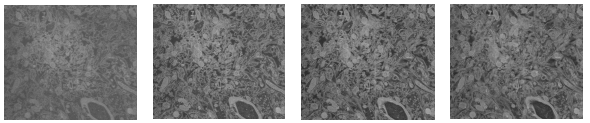


Compensation after auto-functions



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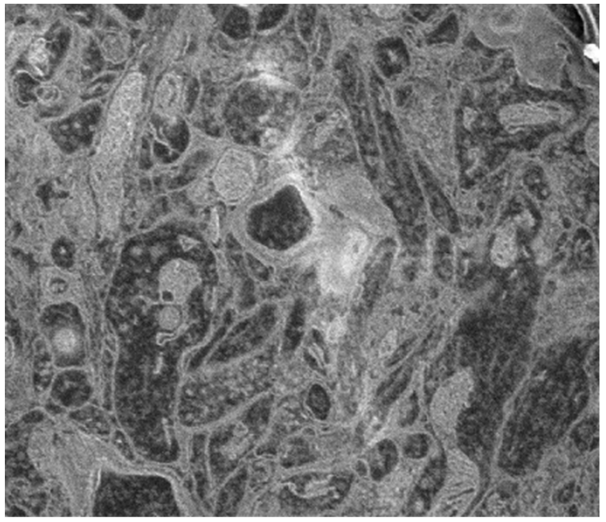
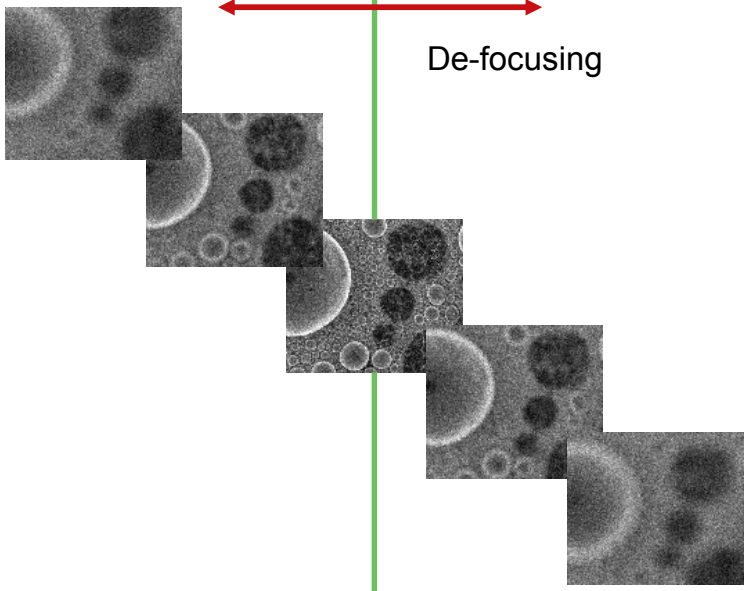


Matlab to test different focusing algorithms

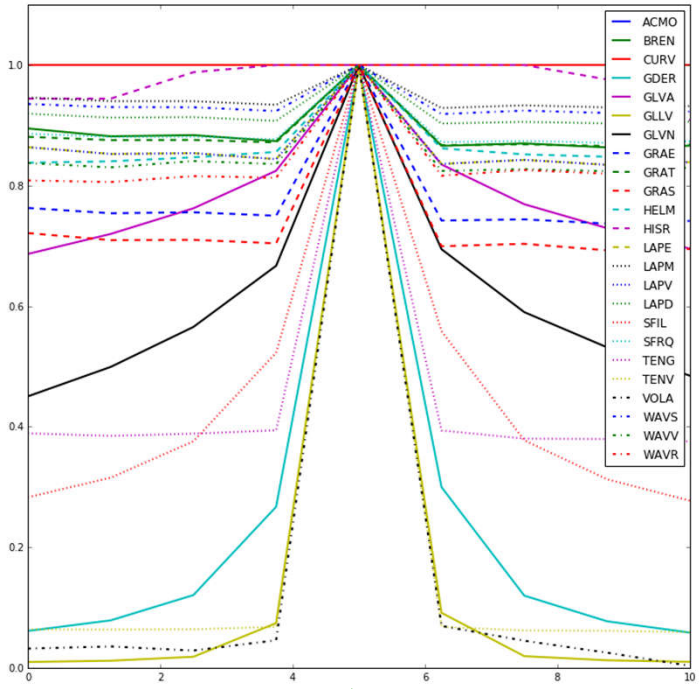
Acquisition + Focus & Processing control in Python

Sharpness algorithms Matlab



De-focusing

In focus



Matlab inline in Python notebook with other languages

Code

In [1]:
```
# XT MPC connection
import pycsharpbridge as pycsharp

ip = get_ipython()
if connect_to_xt:
    ip = get_ipython()
    pycsharp.load_ipython_extension(ip, csharp=kernelExe, socket_addr=kerne
lSocket)
```

C#

Out[1]:
```
Test socket is_kernel_running :tcp://mpc-d0000:9002
Req:{"cmd": "connect"}
.Connected to already running csharp kernel
```

In [2]:
```
# load matlab magic extension
import pymatbridge as pymat

ip = get_ipython()
pymat.load_ipython_extension(ip)
# get the matlab magic module
magic = ip.magics_manager.registry['MatlabMagics']
```

Matlab

Out[2]:
```
Starting MATLAB on ZMQ socket tcp://Matlab-station:54400
Send 'exit' command to kill the server
.........MATLAB started and connected!
```

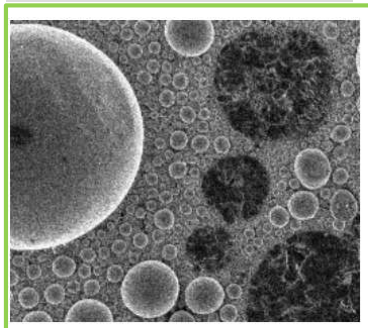
In [3]:
```
# Image acquisition (C#) and sharpness calculation (matlab)

wd = 3.5e-3
%csharp MakeWDsnapshot(wd, 0); -i wd
%csharp ArtImage image = GetImage(0); -o image
display(image.resize((256,221)))

# get sharpness from matlab
%matlab ; -i image
magic.Matlab.run_code(matlabcode)
%matlab ; -o compSharpness
print(NiceFormat(compSharpness))
```

Matlab + C#

Output



```
ACMO:0.06947    64770
BREN:0.0057909  4315.3128
CURV:0.068051   26
GDER:0.037985   3.211550742768305e+35
GLVA:0.021402   37.0071
GLLV:0.031385   7875.9058
GLVN:0.0023444  7.5538
GRAE:0.0051892  2851.0375
GRAT:0.0055283  41.2238
GRAS:0.0024659  1261.0714
HELM:0.034528   1.1402
HISE:0.0067125  0
HISR:0.0010029  219
LAPE:0.0085796  8689.4197
LAPM:0.0062981  101.0271
LAPV:0.0047512  8689.4581
LAPD:0.011362   176.2448
SFIL:0.046259   4.483135721068581e+17
SFRQ:0.0067394  46.3789
TENG:0.006919   19174.2075
TENV:0.007676   358916026.9115
VOLA:0.0054004  5.6804
WAVS:0.23817    30.7009
WAVV:0.045032   97.8731
WAVR:0.099396   0.95287
```

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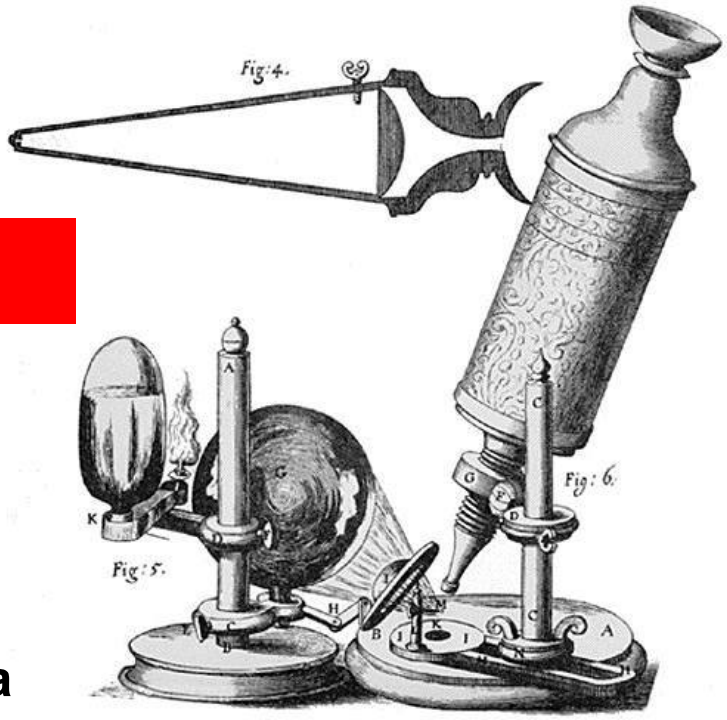
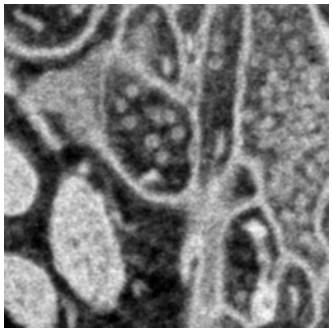
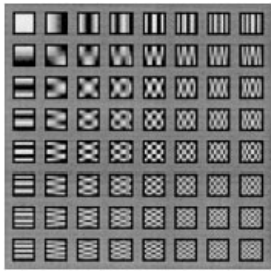


Compressible vs Sparse Signals

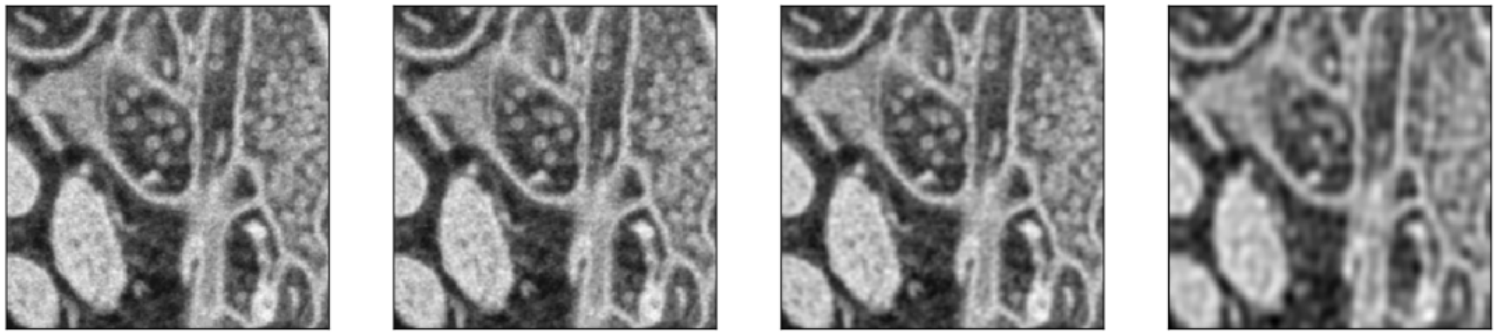


Original

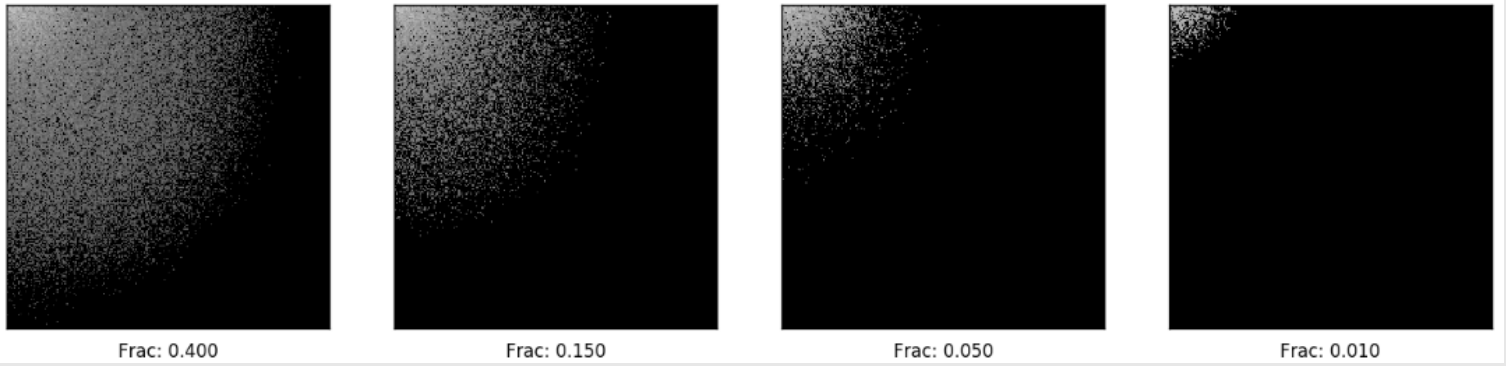


DCT basis

Compressed images – Compressible images – Sparse images

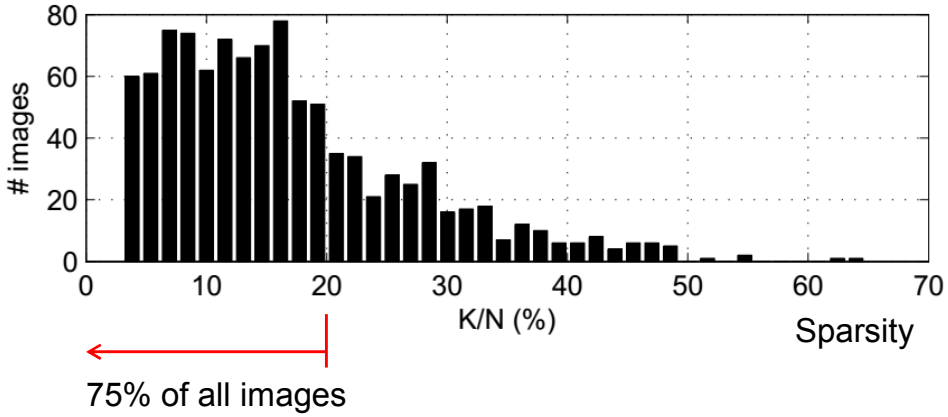


Cropped spectrums



Compressive sensing – motivation from JPEG

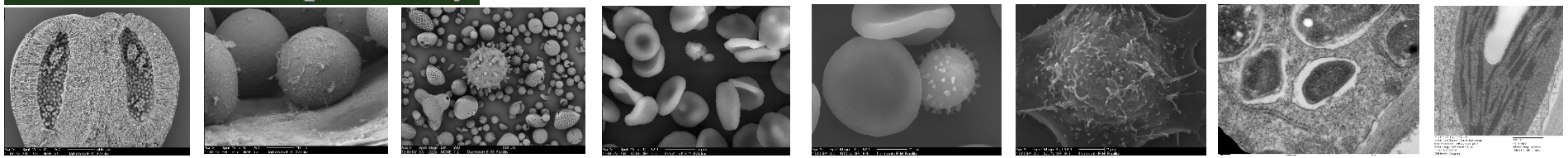
- How sparse is the microscopy image?



Statistics for ~1000images
Sparsity=relative # DCT coefficients for >99.75% energy

2012 Sparse imaging for fast electron microscopy (S.Anderson)

Dartmouth College
Electron Microscope Facility



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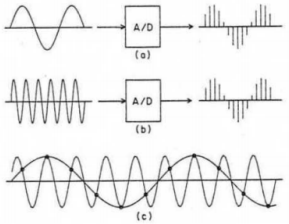
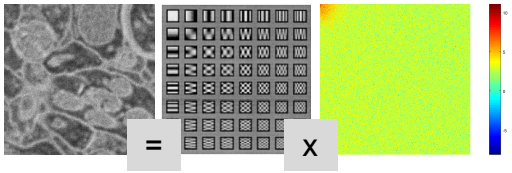
Signal reconstruction for Compressive sensing

- Signal reconstruction from sampling measurements

- Nyquist-Shannon theorem
  # samples depends on the signal's frequencies



- Candes-Tao-Donoho (2004-2006)
  # samples depends on the signal's sparsity



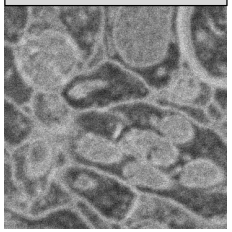
Compressive sensing principle

Measurement process

Reconstruction process

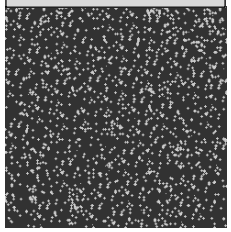
$y' = (\Phi\ \Psi)^{-1}\ m$

Sample



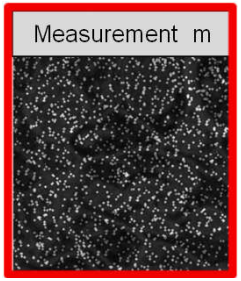
x

Sensing matrix Φ



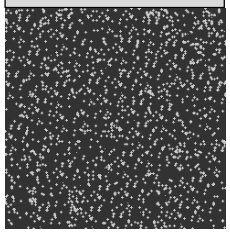
=

Measurement m



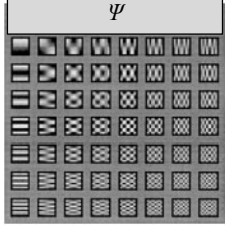
=

Sensing matrix Φ



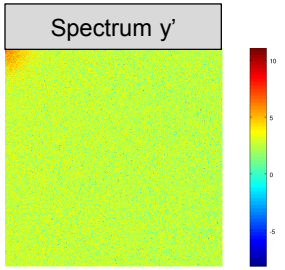
x

Transformation Ψ

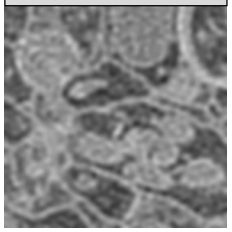


x

Spectrum y'



Reconstructed image i



$i = \Psi\ y$

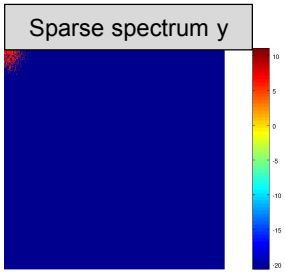
$min\ \|y\|_0$

such that

$m = \Phi\ \Psi\ y$

Iterative searching for…

Sparse spectrum y



Sparse recovery:
- Non-linear optimization that promotes sparsity
- Find the sparsest solution that is consistent with measured data

Sparse undetermined system
Ill-posed problem
(uniqueness is lacking)

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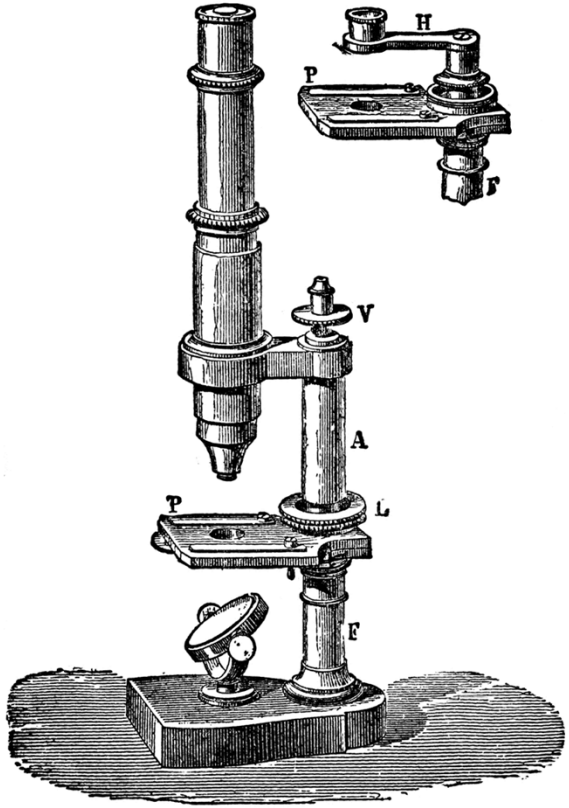
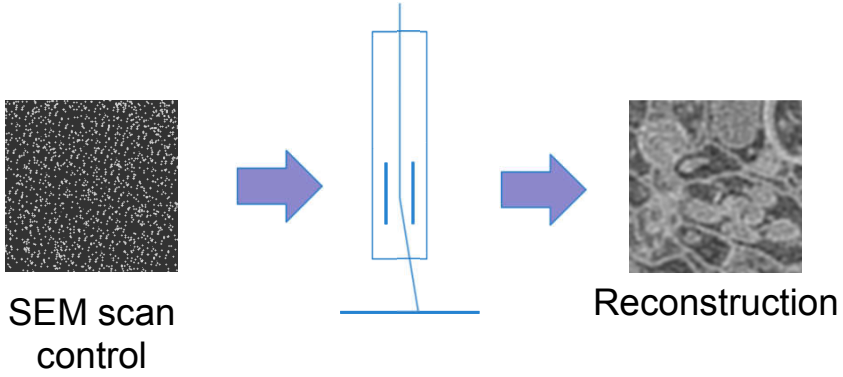
- **Matlab: Reconstruction Algorithms**
- **Matlab Integration: Integration to Acquire Big Data**

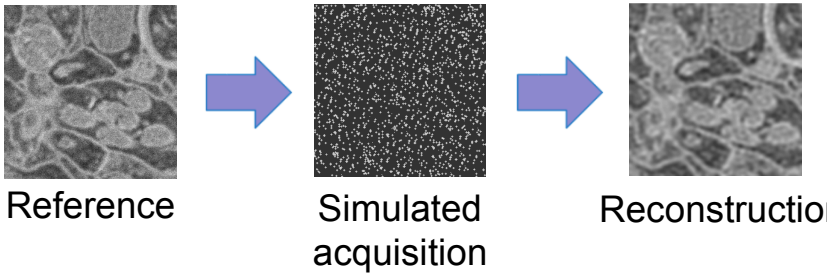


Promise of **high speed** and **low dose** imaging.

- Sparse scanning on SEM/STEM

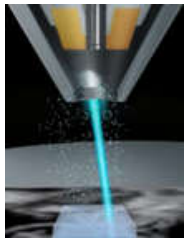


- Reconstruction algorithms

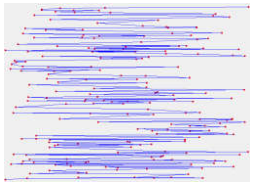


Scanning strategies

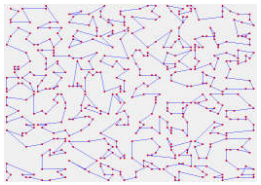
Visiting random positions

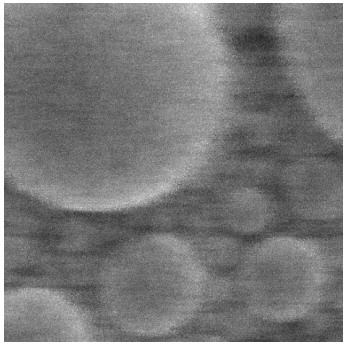


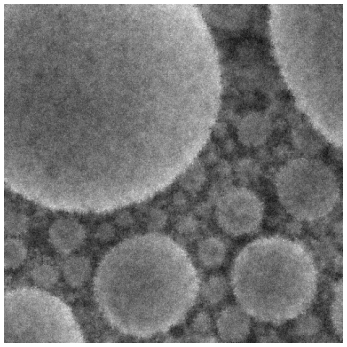
Pseudo-raster

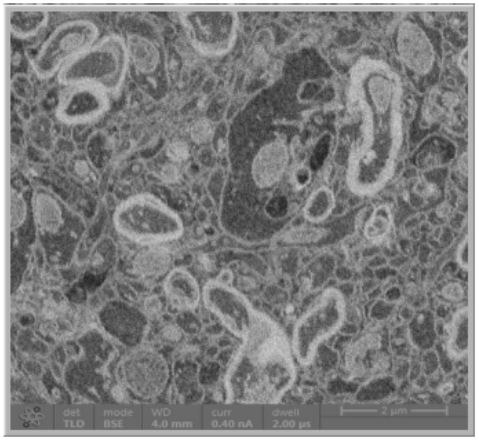


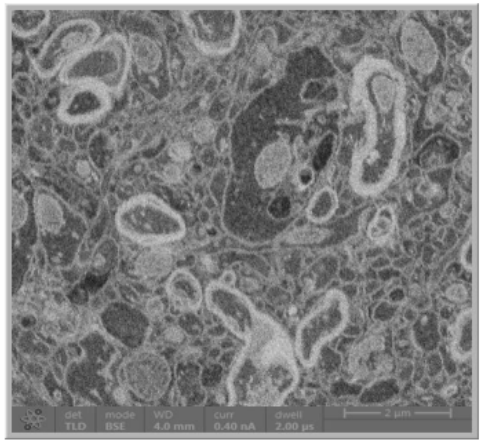
Minimum path scan











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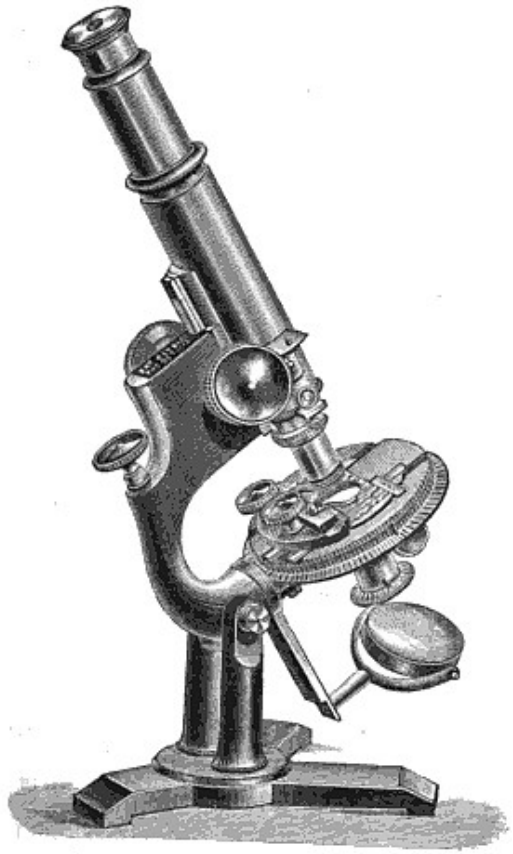
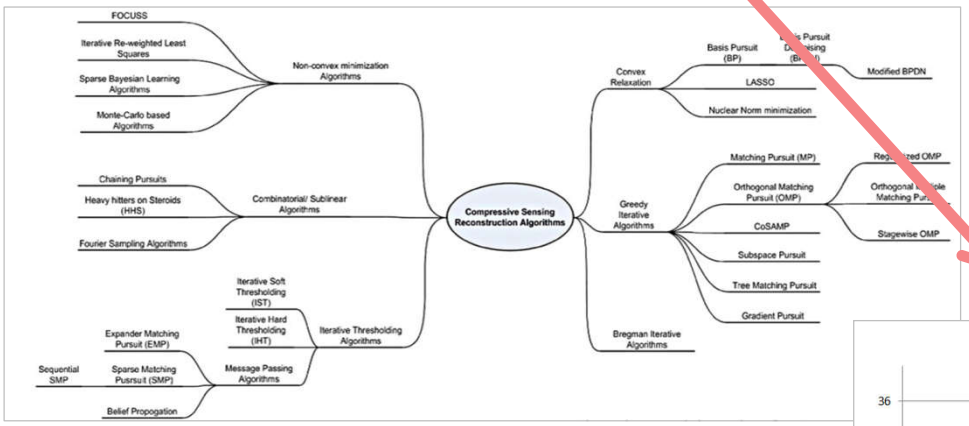
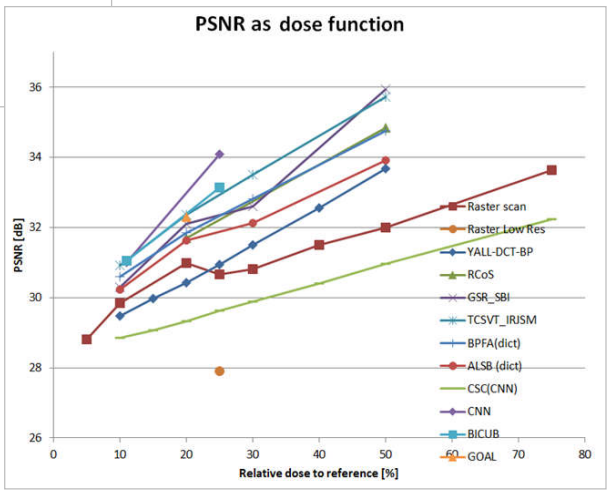


Reconstruction algorithms

Too many in the air …



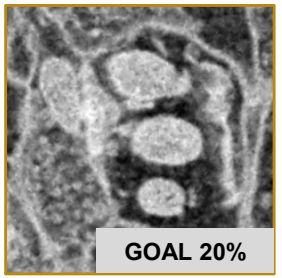
Tested

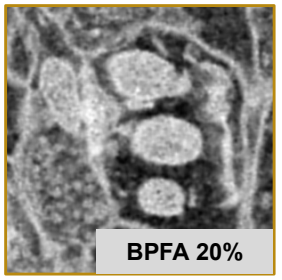


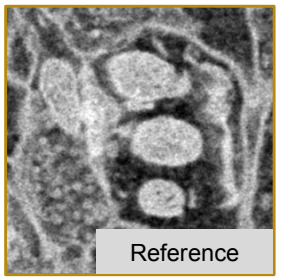
Signal characteristic(s)	Sparsifying transform Ψ
Locally periodic	Discrete cosine (DCT)
Periodic	Fourier (DFT)
Piecewise smooth	Wavelets
Piecewise constant	Finite differences (TV)
Specific	Custom dictionaries

Selected

GOAL – GeOmetric Analysis operator Learning
BPFA – Beta Process Factor Analysis







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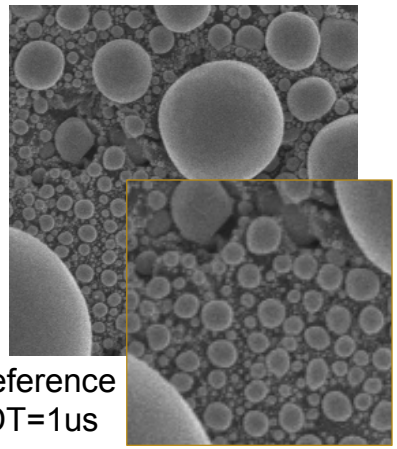
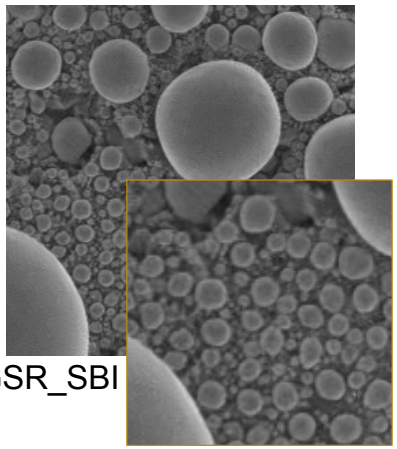
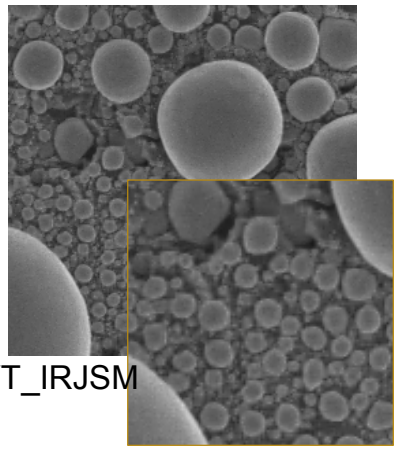
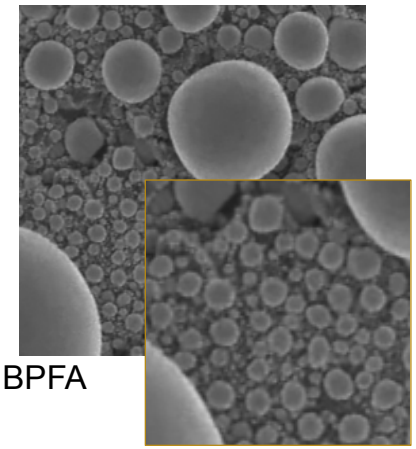
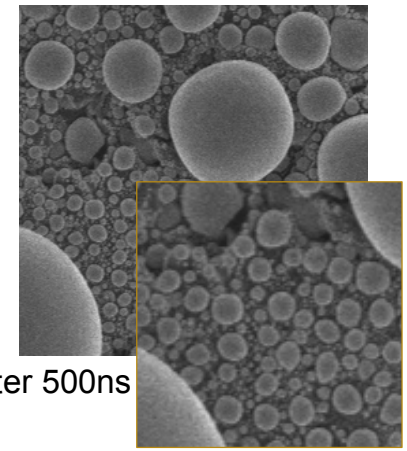
Reconstruction algorithm comparison at 50%

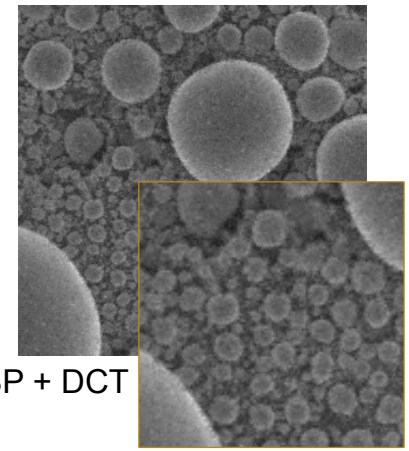

Reference
DT=1us

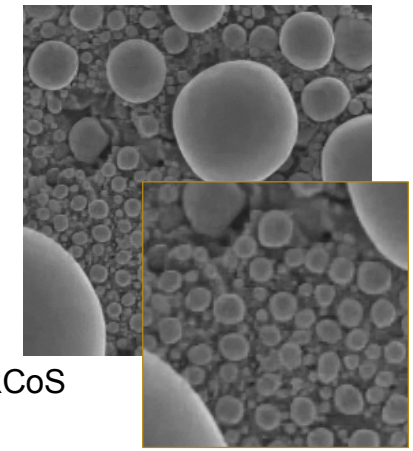

GSR_SBI

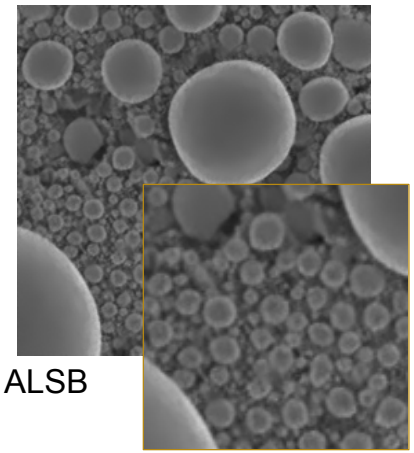

TCSVT_IRJSM


BPFA

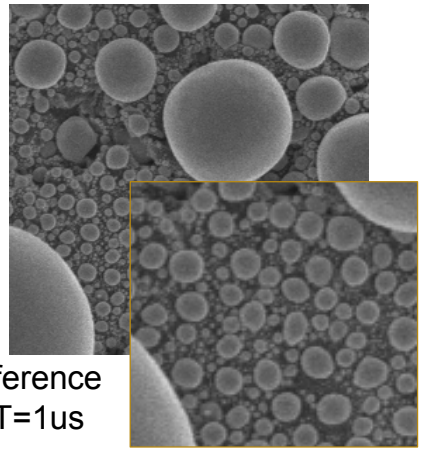

Raster 500ns


BP + DCT

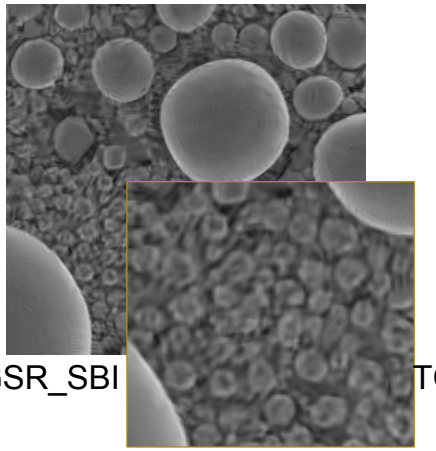

RCoS


ALSB

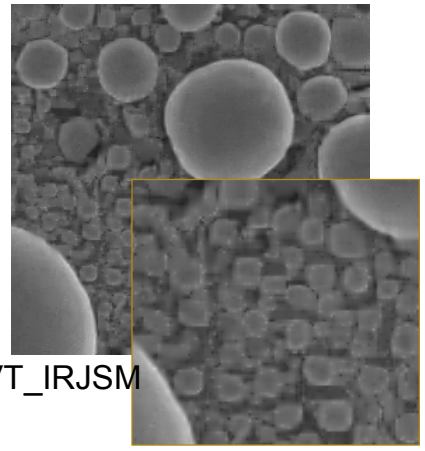
Reconstruction algorithm comparison at 20%



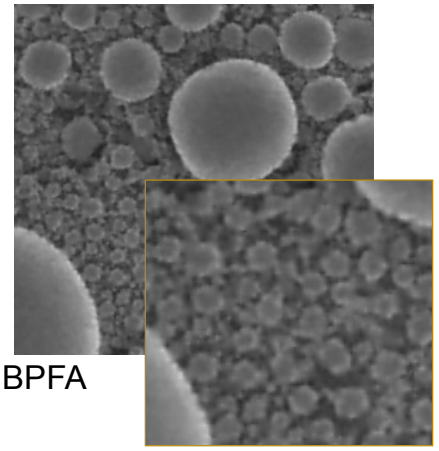
Reference
DT=1us



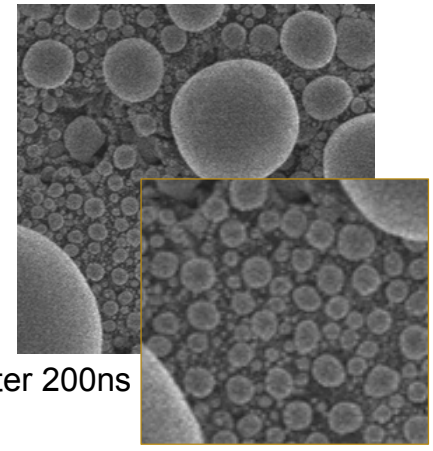
GSR_SBI



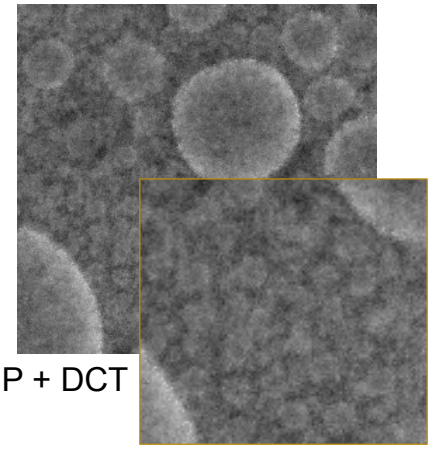
TCSVT_IRJSM



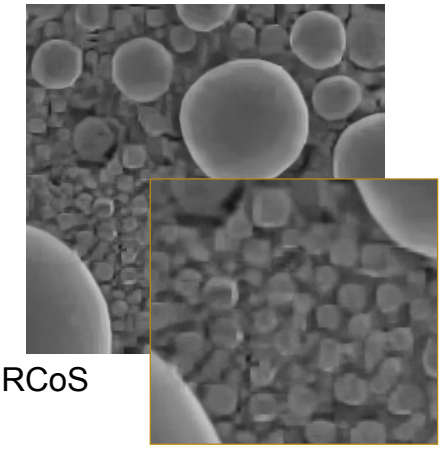
BPFA



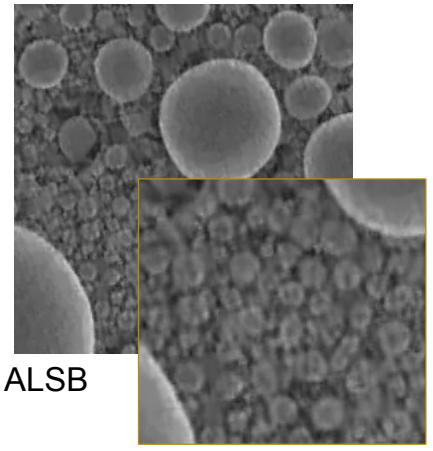
Raster 200ns



BP + DCT



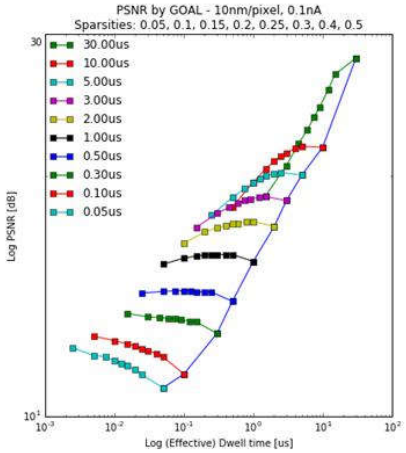
RCoS

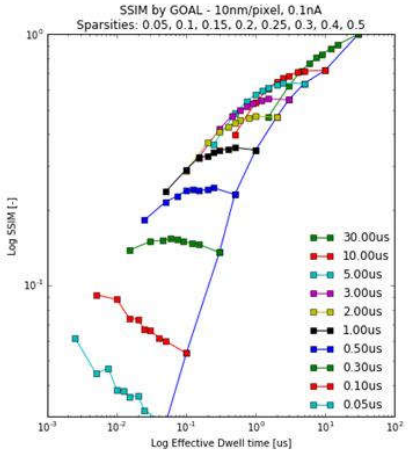


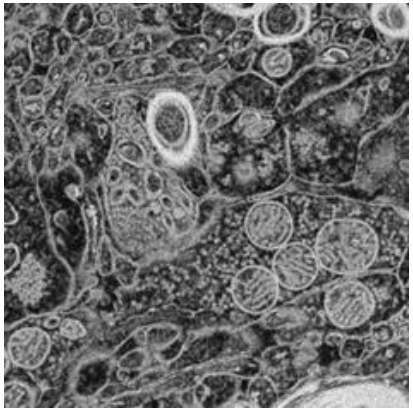
ALSB

Dose-sparsity image quality analysis

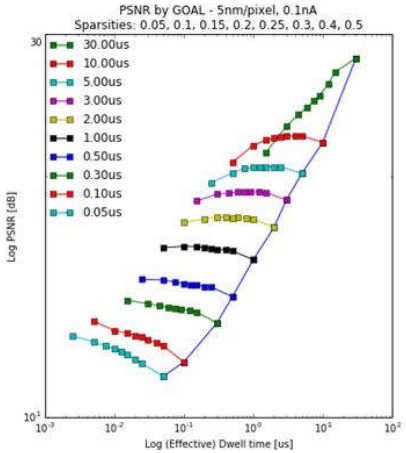
10nm/pixel

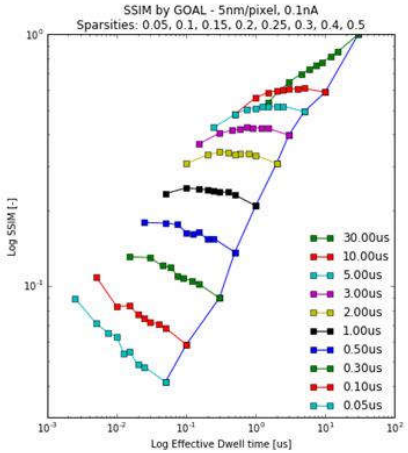


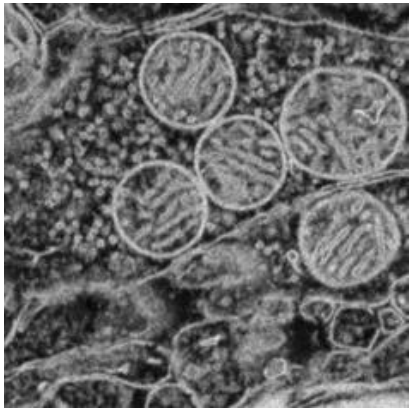




5nm/pixel







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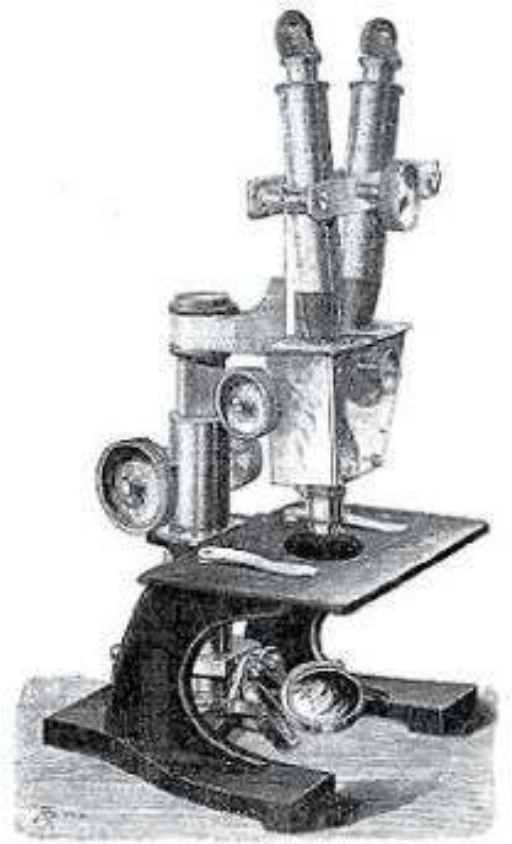
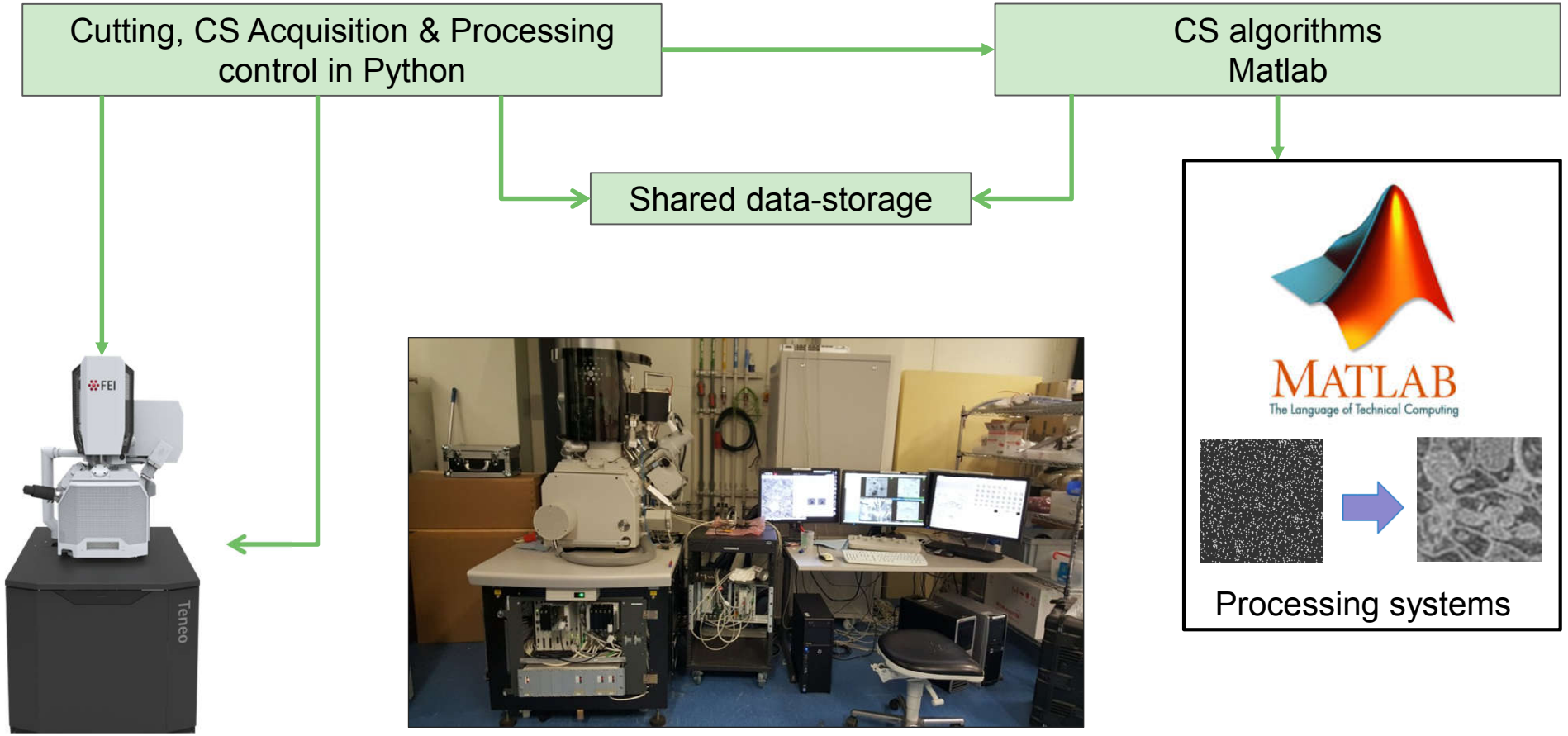
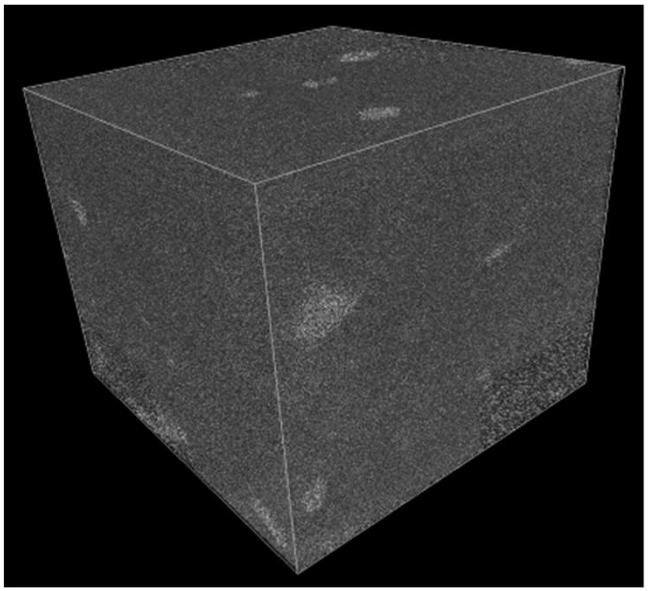


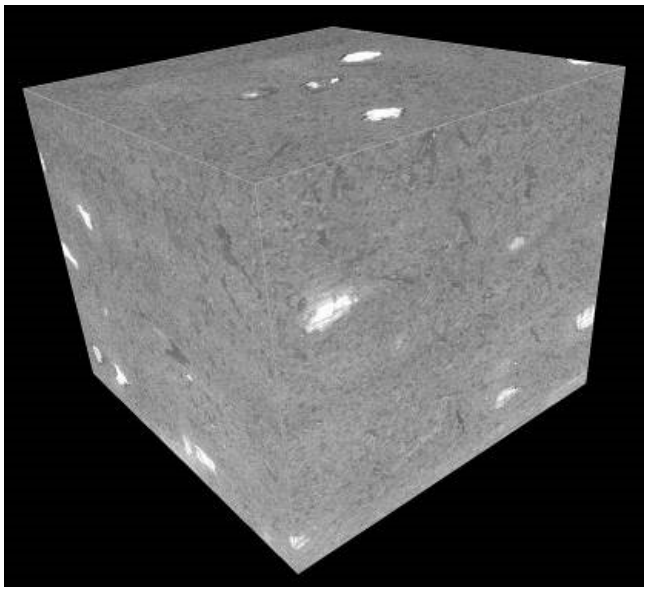
How Matlab helps to evaluate Compressive Sensing?



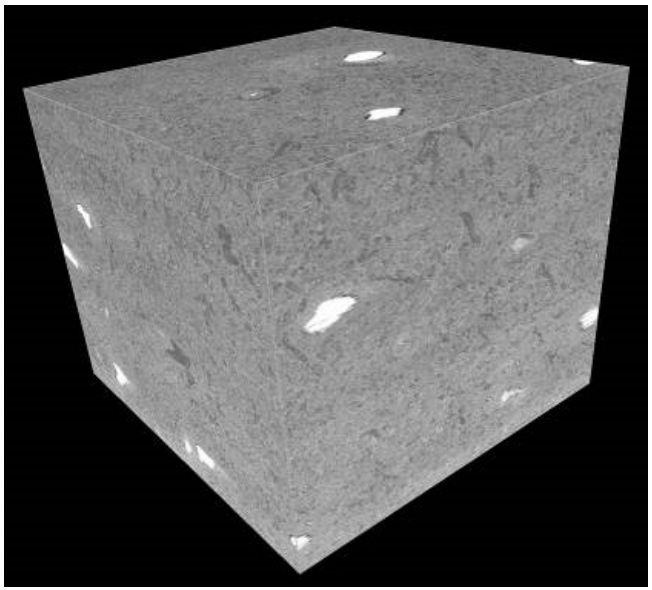
Large Dataset Acquisition - Comparison



Sparse Volume



Reconstruction

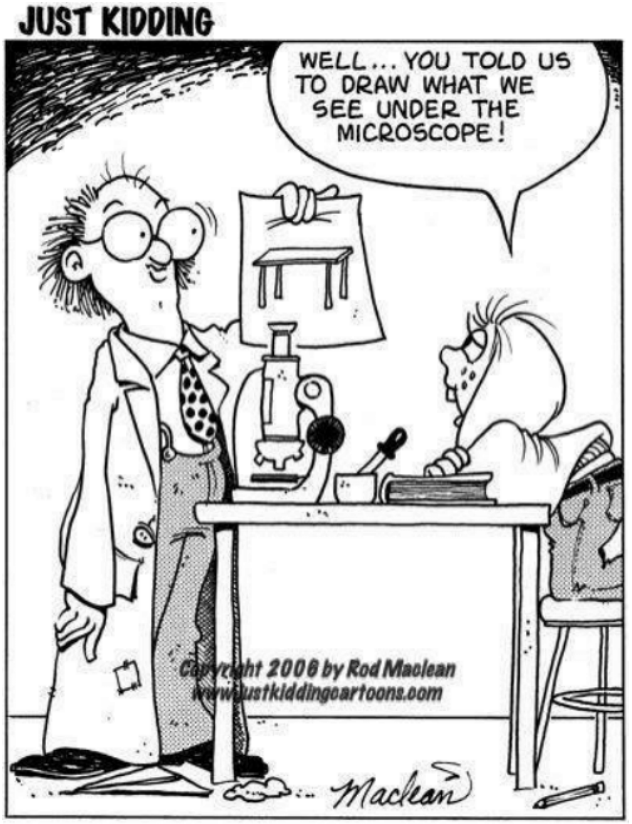


Full Grid Volume

To take away

- **Matlab is a nice computational tool**
- **It is even nicer when integrated in full workflow**
- **It is very good to evaluate algorithms**

  (image sharpness, compressive sensing, …)



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